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PATENT APPLICATION
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System And Method For Determining Light Source Current

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SYSTEM AND METHOD FOR DETERMINING LIGHT SOURCE CURRENT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to co-pending US patent application entitled "System and Method for Scanner Calibration" assigned Serial Number _____ and filed on even date herewith (Attorney Docket Number 10002964).

TECHNICAL FIELD

The present invention is generally related to the field of scanning technology and, more particularly, is related to a system and method for scanner calibration.

BACKGROUND OF THE INVENTION

With the dawn of the information age, scanning technology that is employed to convert paper or other documents into digital documents plays an important role. In particular, scanning technology plays a very important role in reducing the amount of paper that is created in a typical business environment. Scanners contribute to an increase in the speed at which business affairs are conducted. For example, documents that are scanned into digital form may then be transmitted to recipients via the Internet or other network rather than using traditional mail or other couriers.

With all the promise and benefits of scanning technology, it still is plagued with various problems that may often prevent the faithful reproduction of hardcopy documents into digital form. For example, many scanners include inherent imperfections that mar the digital reproduction of scanned documents. Specifically, variations in optics such as lenses employed in scanners may contribute to less than perfect image creation. The various scanner sensors including those within sensor arrays may respond to power supply voltage differently and sensor output voltage ranges may vary from sensor to sensor. Also, variations in sensors generally exist due to process variations during the manufacturing. The light

sources such as light emitting diodes (LEDs) employed in scanners often vary in their performance due to process variations as well.

In addition, typically scanners are plagued with sensor failure over time due to degradation, usage, and incidental damage, etc. For example, in some cases, over time a few sensors may experience failure and constantly emit a single output voltage due to damage or degradation. Such failure may manifest itself in the appearance of vertical streaks or lines in a digital document produced by such a scanner. Unfortunately, it is difficult to counter the effects of such errant sensors.

SUMMARY OF THE INVENTION

In view of the foregoing, the present invention provides for a system and method for determining a light output of a light emitting diode (LED) in a scanner. The present invention advantageously provides an ability to adjust a current flowing through the LED to find an optimum light output, thereby correcting for process variations and other factors that adversely effect the light output of the LED.

In one embodiment, a system is provided for determining a light output of a light emitting diode (LED) in a scanner. According to this embodiment, the system includes a processor circuit having a processor and a memory and an LED current control circuit coupled to the processor circuit and the LED. The LED current control circuit is generally controlled by current control logic stored on the memory and executable by the processor. The current control logic comprises logic for directing the LED current control circuit to apply a first current to the LED for a first time period to generate a first measure of the light output of the LED during the first time period from a number of sensors in a sensor array in the scanner. The current control logic also comprises logic for directing the LED current control circuit to apply an altered current to the LED for a second time period to generate a second measure of the light output during the second time period from the number of sensors in the sensor array, and, logic for comparing a difference between the first measure of the light output and the second measure of the light output with a predefined difference threshold to detect an optimum light output.

In another embodiment, the present invention provides for a method for determining a light output of a light emitting diode (LED) in a scanner. In this

embodiment, the method comprises the steps of applying a first current to the LED to generate the light output of the LED during a first time period, obtaining a first measure of the light output of the LED during the first time period with a number of sensors in a sensor array, applying an altered current to the LED to generate the light output of the LED during a second time period, obtaining a second measure of the light output of the LED during the second time period with the sensors in the sensor array, and comparing a difference between the first measure of the light output and the second measure of the light output with a predefined difference threshold to detect an optimum light output.

The application of predefined currents to the LED's employed in a scanner helps make light output for each LED more uniform.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be understood with reference to the following drawings. The components in the drawings are not necessarily to scale. Also, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. 1 is a drawing of a scanning system that employs scanner calibration logic according to an embodiment of the present invention;

FIG. 2 is a functional block diagram of sensor signal processing circuitry that is manipulated by the scanner calibration logic in the scanning system of FIG. 1;

FIG. 3 is a flow chart of the scanner calibration logic of FIG. 1 according to an aspect of the present invention;

FIG. 4 is a flow chart of a portion of the scanner calibration logic of FIG. 3 executed to determine a minimum dark value of a number of sensors in a sensor array in the scanning system of FIG. 1;

FIG. 5 is a flow chart of a portion of the scanner calibration logic of FIG. 3 executed to determine the current that is applied to the light sources of the scanning system of FIG. 1;

FIG. 6 is a flow chart of a portion of the scanner calibration logic of FIG. 3 executed to determine a saturation exposure time of the sensors in a sensor array in the scanning system of FIG. 1;

FIG. 7A and 7B are a flow chart of a portion of the scanner calibration logic of FIG. 3 executed to determine an operating exposure time of the sensors in a sensor array in the scanning system of FIG. 1;

FIG. 8 is a portion of the scanner calibration logic of FIG. 3 executed to verify the operating exposure time and determine a maximum white value generated by a particular sensor in the sensor array in the scanning system of FIG. 1; and

FIGS. 9A and 9B are a flow chart of a portion of the scanner calibration logic of FIG. 3 executed to verify an analog offset and an analog gain employed in the sensor signal processing circuitry depicted in FIG. 2.

DETAILED DESCRIPTION OF THE INVENTION

Turning to FIG. 1, shown is a scanner 100 according to an aspect of the present invention. The scanner 100 includes a processor circuit with a processor 103 and a memory 106, both of which are coupled to a local interface 109. The local interface 109 may be, for example, a data bus with an accompanying control bus as is generally known by those with ordinary skill in the art. Coupled to the local interface 109 is a scanner drive component interface 113, a sensor signal processing interface 116, and an input/output (I/O) interface 119. The scanner 100 also includes scanner drive components 123 that are coupled to the local interface 109 through the scanner drive component interface 113.

The scanner drive components 123 may include, for example, media drive motors 124, scanner light sources 125, indicator lights, and other components that are employed in the general operation of a scanner 100 as is generally known by those with ordinary skill in the art. The drive motors 124 are employed, for example, to shuttle a scan target such as a paper document or other media along a paper pathway, *etc.* The light sources 125 include three different color lights that illuminate the scan target during the course of a scan operation. For example, the light sources 125 may include red, green, and blue light emitting diodes that generate light that is distributed across a scan target with a light pipe as is generally known by those with ordinary skill in the art.

The scanner 100 also includes a sensor array 129 that is coupled to the local interface 109 through the sensor signal processing interface 116. The sensor array

129 includes a number of sensors 131. The sensors 131 are arranged in a row, for example, to enable the scanning of lines in a document as it progresses through the scanner 100. The sensor array 129 may be, for example, a contact image sensor or other similar device.

5 The sensor signal processing interface 116 includes sensor signal processing circuitry to processes a number of signals produced by the sensors 131 in the sensor array 129 during the course of a scanning operation. The sensor signal processing interface 116 also includes buffering circuitry and/or a memory that provides for the temporary storage of the sensor values obtained from the
10 sensors 131 for access by the processor 103 via the local interface 109. The I/O interface 119 provides the scanner information obtained from a scan operation to a computer system 133 or other device. In addition, the I/O interface 119 facilitates communication with the computer system 133 during the normal operation of the scanner 100 as is generally known by those with ordinary skill in the art.

15 The scanner drive component interface 113, sensor signal processing interface 116, and the input/output interface 119 each include appropriate buffering circuitry as is generally known by those with ordinary skill in the art to make information available to the processor 103. Also, the same components provide various registers to which the processor 103 may write data as is generally known
20 by those with ordinary skill in the art.

The memory 106 may include both volatile and nonvolatile memory components. Volatile components are those that do not retain data values upon loss of power. Nonvolatile components are those that retain data upon a loss of power. Thus, the memory 106 may comprise, for example, random access
25 memory (RAM), read-only memory (ROM), hard disk drives, floppy disks accessed via an associated floppy disk drive, compact disks accessed via a compact disk drive, magnetic tapes accessed via an appropriate tape drive, and/or other memory components, or a combination of any two or more of these memory components.

In addition, the processor 103 may represent multiple processors and the
30 memory 106 may represent multiple memories that operate in parallel. In such a case, the local interface 109 may be an appropriate network that facilitates communication between any two of the multiple processors or between any processor and any of the memories, etc. The local interface 109 may facilitate

memory to memory communication as well. The processor 103, memory 106, and local interface 109 may be electrical or optical in nature. Also, the memory 106 may be magnetic in nature.

The scanner 100 includes various components that are stored on the memory 106 and executable by the processor 103 in performing the functionality of the scanner 100. In particular, stored on the memory 106 is an operating system 143 and a scanner control system 146. The scanner control system 146 includes scanner calibration logic 149 and a sensor validity table 153. The operating system 143 is executed to control the allocation and usage of hardware resources in the scanner. Specifically, the operating system 143 controls the allocation and usage of the memory 106 and processing time, *etc.* The scanner control system 146 is executed by the processor 106 to control the general operation of the scanner 100. In particular, the scanner control system 146 controls the activation of the drive motors 124, light sources 125, and other aspects of the scanner 100. According to an aspect of the present invention, the scanner calibration logic 149 is executed by the processor 103 to perform the calibration of the scanner 100. The specific details of the scanner calibration logic 149 are discussed in detail in the figures that follow.

Next a brief overview of the operation of the scanner 100 is provided.

Assuming that a user wishes to scan a document or other media to create a digital copy, the document or other media is placed into a receiving slot of the scanner 100 as is generally known by those with ordinary skill in the art. The user then initiates the scan in a conventional manner by manipulating an input device, *etc.* The scanner control system 146 then controls the operation of the scanner drive components 123 including the drive motors 124, light sources 125, and other components in synchronization with the scanning function of the sensor array 129 to obtain the digital representation of the hard copy document. The digital information is then provided to a computer system 133 or other device by way of the I/O interface 119.

The scanning of the digital document is accomplished by repeatedly scanning "lines" of pixels from the digital document. To scan a line of pixels from the document, each of the light sources 125 is consecutively illuminated for a predetermined exposure time, thereby illuminating the document to be scanned.

Note that the exposure time may be independently set for any time period desired and is altered more than once during the calibration of the scanner 100 as will be described. For each of the light sources 125, each of the sensors 131 absorbs the light reflected from the document and generates a sensor value therefrom. The
5 sensor values are then read out of the sensor array 129 and accessed by the processor 103 via the sensor signal processing interface 116. Note that the sensor values are conditioned by sensor signal processing circuitry within the sensor signal processing interface 116 as will be discussed.

In order to scan the hard copy document to obtain a faithful digital
10 reproduction, according to the present invention the scanner 100 is calibrated for optimal operation. To calibrate the scanner 100, the scanner calibration logic 149 is executed by the processor 103. The scanner calibration logic 149 may be executed before the scanning of each document or at user defined times based upon a predefined user input. Alternatively, the scanner calibration may be
15 performed after predefined amount of scanner usage. Regardless of when the scanner calibration logic 149 is executed, the execution thereof ensures the optimal operation of the scanner 100.

With reference then to FIG. 2, shown is a functional block diagram of the sensor signal processing circuitry 116a within the sensor signal processing
20 interface 116. A discussion of the sensor signal processing circuitry 116a is provided to give context to the various functions performed during the execution of the scanner calibration logic 149 (FIG. 1). To begin, the sensor signal processing circuitry 116a receives a serial stream of sensor values from the sensors 131 (FIG. 1) in the sensor array 129 (FIG. 1). These values are applied to a programmable
25 gain amplifier 156. The programmable gain amplifier 156 is employed to apply an analog offset 159 and an analog gain 163 to the sensor values.

Thereafter, the sensor values are applied to an analog-to-digital (A/D)
converter 166 to convert the sensor values in digital form. The digital sensor values are then applied to a digital offset subtractor 169 that subtracts a digital offset from
30 the digital values. Specifically, the sensor signal processing circuitry 116a includes a memory 173 within which is stored a digital offset/gain table 176. A sensor offset and a digital gain are maintained in the digital offset/gain table 176 for each of the sensors 131. After the digital offset is subtracted from the sensor values in the

digital offset subtractor 169, the sensor values are applied to the digital amplifier 179 that amplifies the sensor values by the respective digital gains stored in the memory 173. Thereafter, the sensor values are applied to a nonlinear converter 183 that generates the sensor value output 186 that is applied to appropriate buffer circuitry and/or other circuitry to be accessed by the processor 103 (FIG. 1) through the local interface 109 (FIG. 1).

The sensor values that are generated by the individual sensors 131 in the sensor array 129 generally fall within a predetermined sensor output voltage range. This range may be, for example, 1.2 volts through 2 volts or other voltage window as is generally known by those with ordinary skill in the art. Unfortunately it is not always the case that the sensor values fall within this range. For example, due to degradation of the sensors 131 over time, some sensors may malfunction producing a continuous high or low voltage value. Others may provide a sensor value that is proportional to the intensity of the incident light, but the range may extend beyond the predefined sensor output range.

As a consequence, it is possible that one or more sensor values may be generated by one or more malfunctioning sensors 131 during the course of a scan that are clipped high and clipped low by the A/D converter 166. To address this problem, the analog offset 159 and the analog gain 163 are applied to the programmable gain amplifier 156 to ensure that all sensor values received from the sensors in the sensor array 129 fall within the input window of the A/D converter 166. Note however, that some sensors may not be able to produce a sensor value that falls within the input voltage range of the A/D converter 166 even with the application analog offset 159 and/or the analog gain 163. In such case, the present invention provides for the sensor validity table 153 that is employed to track malfunctioning sensors 131 and the sensor values that they generate are ignored.

Given that the output voltage range of the sensors 131 may vary from sensor to sensor, the present invention outlines an approach by which the minimum dark value and the maximum white value generated among all of the sensors in the sensor array 129 are identified. Once these values are known, the analog offset 159 and the analog gain 163 are set to ensure that all of the output voltage ranges of the sensors 131 fall within the input range of the A/D converter 166.

With reference to FIG. 3, shown is a flow chart of the scanner calibration logic 149 according to an embodiment of the present invention. Alternatively, the flow chart of FIG. 3 may be viewed as depicting the steps in a calibration method implemented in the scanner 100 (FIG. 1). The scanner calibration logic 149 is executed by the processor 103 (FIG. 1) to calibrate the operation of the sensor signal processing circuitry 116a (FIG. 2). The scanner calibration logic 149 ensures that the analog offset 159 and the analog gain 163 are set so as to obtain sensor values from the sensors 131 that represent valid and accurate imaging information. In addition, the scanner calibration logic 149 identifies any malfunctioning sensors 131 within the sensor array 129 and tracks them in the sensor validity table 153. This is done so that any malfunctioning sensors 131 may be ignored during a scanning operation, thereby eliminating undesirable abnormalities in the resulting image.

The scanner calibration logic 149 in FIG. 3 begins with block 203 in which a minimum dark value of all the dark sensor values generated by the sensors 131 (FIG. 1) is identified. The dark values represent those sensor values that are generated with no light from the light sources 125 (FIG. 1). To determine the minimum dark value, the scanner calibration logic 149 executes a dark value subroutine as will be discussed. Thereafter, the scanner calibration logic 149 moves to block 206 in which an amount of current that flows through the light sources 125 is determined. Assuming, for example, that the light sources 125 are light emitting diodes (LEDs), then the intensity of light that they generate may vary from light source to light source for a number of reasons. The scanner calibration logic 149 executes a "current subroutine" to determine and set the magnitude of the currents that flow through the respective light sources 125 to ensure that each generates light of a desired intensity. In order to set the magnitude of the currents that flow through each of the light sources 125, a current control circuit that drives each of the light sources 125 is controlled by the current subroutine as will be discussed.

Thereafter, in block 209 the scanner calibration logic 149 determines a saturation exposure time for each of the sensors 131 by executing a "saturation subroutine". Then, in block 213, an optimal exposure time is determined for each of the light sources by the execution of an "exposure time subroutine". The

scanner calibration logic 149 then moves to block 216 in which the exposure times for each of the light sources 125 is verified and a maximum white value of all the maximum white sensor values is determined. This is accomplished with the execution of an exposure time verification subroutine that will be described.

5 Thereafter, in block 219 the scanner calibration logic 149 calculates the analog gain 163 based upon the maximum white value determined in block 216 and the minimum dark determined in block 203. In block 223, the analog offset is determined based upon the minimum dark value 203. Next, in block 226 the analog offset 159 and the analog gain 163 are verified and in block 229 a digital gain and a digital offset are determined for each of the sensors 131 and placed in the digital offset/gain table 176 (FIG. 2). The following discussion provides further detail on select ones of the above tasks performed by the scanner calibration logic 149.

15 Referring next to FIG. 4, shown is a flow chart of the dark value subroutine 203 that is executed to determine the minimum dark value out of all the dark values generated by the sensors 131 (FIG. 1) in the sensor array 129 (FIG. 1). Alternatively, the flow chart of FIG. 4 may be viewed as depicting steps in a method to determine the minimum dark value among all of the dark values generated by the sensors 131 of the sensor array 129.

20 Beginning with block 240, the dark value subroutine sets the analog gain 163 (FIG. 2) to unity. Next, in block 242 the analog offset is increased to a value that places the bottom of the operating voltage range of the sensors into the mid-region of the input voltage range of the A/D converter 166 (FIG. 2). This is done to ensure that all the dark values that are generated by the sensors 131 fall within the output voltage range of the A/D converter 166. Thereafter, in block 244 the exposure time of the light sources 125 (FIG. 1) is set to "0" to ensure that the light sources 125 are continually turned off to obtain dark values from the sensors 131 in the sensor array 129 (FIG. 1). Thereafter, in block 246 a scan of the sensors 131 is performed to obtain a dark value for each of these sensors 131 in the sensor array 129.

30 Next, in block 248, the dark value subroutine 203 ascertains whether the dark values of any of the sensors 131 are at or below the bottom value of the output range of the A/D converter 166. The bottom value may be, for example,

zero or other value. If such is the case then the dark value subroutine 203 moves to block 250 in which each sensor 131 that has been clipped at the bottom of the output range of the A/D converter 166 is disqualified from further calculations and from further use in image generation. This is accomplished by placing an

5 appropriate value in a register in the sensor validity table 153 that corresponds with the particular sensor in question indicating that the respective sensor 131 is invalid. The dark value subroutine 203 then proceeds to block 252 as shown. However, assuming that no dark values from any of the sensors 131 fall below the bottom of the output range of the A/D converter 166, then the dark value subroutine 203
10 moves directly to block 252.

In block 252, the dark value subroutine 203 determines whether any of the dark values obtained from any of the sensors 131 in the sensor array 129 are greater than or equal to the upper limit of the output range of the A/D converter 166. The upper limit may be a value of 1023, for example, assuming ten bit parallel
15 output bus, although other values may be employed. If so then the dark value subroutine 203 progresses to block 254. Otherwise, the dark value subroutine 203 jumps to block 256. Assuming that the dark value subroutine 203 has proceeded to block 254, then at least one of the dark values from the sensors in the sensor array 129 has produced a dark value that falls at or above the upper limit of the operating
20 output range of the A/D converter 166. Consequently, the sensor array 131 is further checked to determine whether the errant sensors 131 can produce valid sensor values.

To do so, in block 254 a predetermined value is subtracted from the analog offset 159 (FIG. 2). Thereafter, in block 258 a scan is performed obtaining new
25 dark values from each one of the sensors 131, the new dark values being stored in the memory 106. Thereafter, in block 260 each sensor 131 that produces a dark value that is still above the upper limit of the operating output range of the A/D converter 166 is disqualified in the sensor validity table 153.

In block 256 the dark value subroutine 203 determines which of the dark
30 values from all of the remaining qualified sensors 131 is the minimum dark value. Thereafter, in block 262, the analog offset 159 is set to a value that causes the minimum dark value to fall just above the lower limit of the operating output range of the A/D converter 166 by a predefined amount. Thereafter, in block 264, a scan

is performed of the sensors 131 and the sensor values obtained therefrom are stored for later calculation. Thereafter, in blocks 266, the new minimum dark value from these sensor values is determined and stored in the memory 106 (FIG. 1).

Thereafter the dark value subroutine 203 ends as shown.

5 Turning then to FIG. 5, shown is a flow chart depicting the current subroutine 206 that is executed in conjunction with the scanner calibration logic 149 (FIG. 3) to determine an optimum current that is to flow through each of the light sources 125 (FIG. 1) that may be light emitting diodes or other light sources. The current subroutine 206 is included to control the current flowing through the light sources
10 insofar as the intensity of the light that is created thereby varies with the amount of current flowing therethrough.

Beginning with block 280, the current subroutine 206 first determines the maximum exposure time for each colored light source 125 employed in the scanner 100. Note that the maximum exposure time may depend upon various factors
15 including the speed at which the document progresses through the scanner 100 (FIG. 1) and the resolution of the sensors 131 (FIG. 1) employed to obtain the images from the document, *etc.* Thereafter, in block 282, the exposure time for each of the light sources 125 is set to the maximum allowable. This may be, for example, one third of the total time allotted to acquire a single line of pixels in a
20 document as all color information is often acquired for a single row of pixels as is generally owned by those with ordinary skill in the art.

Thereafter, in block 284 the magnitude of the current that flows through the respective light sources is set to a minimum value generated by an accompanying current control circuit in the scanner 100 such as the current control circuit
25 discussed in United States Patent Application entitled "System and Method for Illuminating Light Emitting Diodes in a Contact Image Sensor" assigned serial number 09/776,069 filed on February 2, 2001. Then, the current subroutine 206 moves to block 286 in which a scan of the sensors 131 is performed and the sensor values obtained therefrom are stored in the memory 106. Thereafter, in block 288,
30 all of the currents that flow through the respective light sources 125 that are not set to a finalized value are incremented by a predetermined amount by manipulating the current control circuit. Note that the first time that block 288 is encountered, all

of the light emitting diode currents will not be set to a final value as the optimal current level for each has yet to be determined.

The current subroutine 206 then proceeds to block 290 in which a scan is performed of the sensors 131 and the corresponding sensor values are stored in the memory 106. Note that the newly determined current values from block 288 are applied to the light sources during the scan performed in block 290. Thereafter, in block 292 a loop is begun for each light source.

In block 294, the current sensor values are compared to the previous sensor values to determine whether the new values are greater than the previous values by a predetermined percentage increase. Thereafter, in block 296, if the current sensor values are greater than the prior sensor values by the predetermined percent increase, then the current subroutine 206 proceeds to block 298. On the other hand, if the percent increase has not been achieved in block 296, then the current subroutine 206 proceeds to block 300 in which the current for the present light emitting diode is set to the previous setting. Thereafter the current subroutine 206 progresses to block 298. In block 298, it is determined whether the comparison of block 294 has been performed for all of the light sources. If not, then the current subroutine 206 proceeds to block 302 in which the next light source is identified. Otherwise, the current subroutine 206 proceeds to block 304. Once the next light source is identified in block 302, then the current subroutine 206 reverts back to block 294.

In block 304, the current subroutine 206 determines whether all of the currents for each of the light emitting diodes and their corresponding colors has been set in block 300, or are at the maximum allowed current. If not, then the current subroutine 206 reverts back to block 288. Otherwise, the current subroutine 206 ends.

Thus, the current subroutine 206 establishes the optimum current to flow through the respective light sources by starting at a low current value and increasing the currents in steps until a saturation of the sensors 131 is detected. Note that the percent increase that is compared with respect to block 296 may be, for example, eight percent or other value.

Alternatively, a different approach in which the currents applied to the sensors 131 are decremented. For example, initially in block 284, the currents may

be set to a minimum and the unset currents may be decremented in block 288. In such case, in block 296, the current subroutine 206 would detect a predefined percent decrease that indicates the saturation point of the sensors 131 has been reached.

5 Turning to FIG. 6, shown is a flow chart of a saturation subroutine 209 that is employed to find the sensor saturation level of each of the sensors 131 (FIG. 1) of the sensor array 129 (FIG. 1). Alternatively, the flow chart of FIG. 6 may be viewed as depicting steps in a method for determining the sensor saturation levels of the sensors 131. For each of the sensors 131 in the sensor array 129, there are three
10 different saturation levels, one for each colored light source 125 (FIG. 1). The saturation subroutine 209 is executed to determine the exposure time at which most or all of the sensors 131 are near saturation, but not actually in a saturated condition. Beginning with block 320, the exposure time for the light sources 125 is set to a maximum possible value as may be determined by one with ordinary skill in
15 the art. This may be determined, for example, by examining the speed at which a scanned document progresses through the scanner 100 (FIG. 1) to determine the maximum amount of time that each of the light sources 125 can be illuminated.

Next, in block 322, a scan of the sensors 129 is performed at the maximum exposure time and an initial set of sensor values obtained therefrom is stored in the
20 memory 106 (FIG. 1). Then, in block 324, any of the sensors that produce sensor values that are less than a predetermined minimum threshold are disqualified from further operation in the sensor validity table 153 (FIG. 1). This is because at the maximum exposure time, all of the sensors 131 within the sensor array 129 should produce sensor values of appreciable magnitude. Those sensors 131 that do not
25 produce such a sensor value are presumed to be malfunctioning. Next, in block 326 the exposure time is reduced by a predetermined value. Thereafter, in block 328 another scan of the sensors 131 is performed and the sensor values obtained therefrom are stored in the memory 106. Then, in block 330 a loop is executed for each of the sensors 131. Thereafter in block 332, the most recent sensor value
30 obtained for the current sensor 121 is compared with the second most recent sensor value obtained from the same sensor 131.

In block 334, if the most recent sensor value is greater than the second most recent sensor value for a particular sensor, then the saturation subroutine 209

progresses to block 336. Otherwise the saturation subroutine 209 moves to block 338. In block 336, the most recent sensor value obtained for the current sensor is stored as the sensor saturation level. Thereafter the saturation subroutine 209 proceeds to block 340. On the other hand, in block 338, the second most recent
5 sensor value is stored as the sensor saturation level. Thereafter the saturation subroutine 209 proceeds to block 340. In block 340, it is determined whether the last pair of sensor values has been compared, given that there are three different colors to compare for each sensor within the sensor array 129. Assuming that more pairs of sensor values remain to be analyzed in block 340, then the saturation
10 subroutine 209 proceeds to block 342 in which the next pair is identified. Thereafter, the saturation subroutine 209 reverts back to block 332.

However, if in block 340 it is determined that the last pair of sensor values has been analyzed, then the saturation subroutine 209 proceeds to block 344. In block 344 it is determined whether the final saturation levels have been determined
15 for all of the sensors 131 in the sensor array 129 or if minimum exposure time values have been reached. The final saturation levels are determined when the second most recent sensor values are stored as the saturation levels in block 338. This is because a subsequent sensor reading at a lower exposure time did not change the saturation level itself. The minimum exposure time detected in block
20 344 is a predetermined value that is ascertained based upon what should be a minimum exposure time for the saturation levels to be obtained by the sensors 131. If either condition is true in block 344, then the saturation subroutine 209 ends. However, if not, then the saturation subroutine 209 reverts back to block 326. Thus, the saturation subroutine 209 obtains an estimate of the exposure time at
25 which each of the sensors 129 is saturated for each individual color. This information is employed to obtain the optimum exposure time as will be discussed.

With reference to FIGS. 7A and 7B, shown is a flow chart of an exposure time subroutine 213 that is executed to determine the optimal exposure times of the sensors 131 (FIG. 1) in block 213 (FIG. 3). Alternatively, the flow chart of FIGS. 7A
30 and 7B may be viewed as depicting the steps in a method for determining an optimal exposure time of the sensors 131. The exposure time subroutine determines the optimal exposure times of the sensors 131 by repeatedly reducing the exposure time and scanning the sensors 131 to arrive at sensor values that are

at least a predetermined percentage below the saturation level for each sensor 131.

Referring to FIG. 7A, in block 360 the exposure time for the light sources 125 is set to a "gray" exposure time. The gray exposure time is somewhere between the maximum possible exposure time and a minimum exposure time of zero. Once the exposure time is set to the gray exposure time in block 360, the exposure time subroutine 213 proceeds to block 362 in which the sensors in the sensor array 129 are scanned and the resulting sensor values are stored in the memory 106 (FIG. 1).

Thereafter the exposure time subroutine 213 proceeds to block 364 in which a first sensor value is identified among the sensor values stored in block 362. In block 366 the current sensor value identified is compared with the sensor saturation level for the particular sensor for the corresponding color. Then, in block 368 it is determined whether the sensor value is less than the sensor saturation level by at least a predetermined amount. The predetermined amount may be, for example, fifteen percent of the sensor saturation level or other number as is appropriate. If such is the case, then the exposure time subroutine 213 proceeds to block 370. Otherwise, the exposure time subroutine 213 proceeds to block 372.

In block 370 it is determined whether the last sensor value stored in block 362 has been compared with the corresponding sensor saturation level for the particular sensor of the sensor array 129. If not, then the exposure time subroutine 213 proceeds to block 374 in which the next sensor value stored in the memory 106 is identified. Thereafter the exposure time subroutine 213 reverts back to block 366. On the other hand, if it is determined in block 370 that the last sensor value has been evaluated, then the exposure time subroutine 213 proceeds to the connector C1 as shown.

Assuming that the exposure time subroutine 213 has proceeded to block 372, then it is determined whether the exposure time has experienced a predetermined number of reductions from the original gray exposure time ascertained in block 360. In essence, the exposure time subroutine 213 only reduces this value by a predetermined number of times to obtain sensor values that are at least fifteen percent or other predetermined value lower than the corresponding sensor saturation level.

In block 372, the exposure time subroutine 213 determines whether the last reduction of the exposure time has occurred. If not then the exposure time subroutine 213 proceeds to block 376. Otherwise the exposure time subroutine 213 proceeds to block 378. In block 376, the exposure time is reduced, for example, by dividing it by two. Note that this reduction may be accomplished in another manner, for example, by decrementing the exposure time by a specific amount, dividing by a number other than two, or by some other approach. After block 376, the exposure time subroutine 213 reverts back to block 362 in which the sensors 131 of the sensor array 129 are scanned once again.

Assuming that the exposure time subroutine 213 proceeds to block 378, then the final reduction of the exposure time has occurred and the sensor value of the current sensor under consideration still remains above the predetermined threshold of fifteen percent below the sensor saturation level. In block 378, this sensor is disqualified as it is assumed to be malfunctioning. Thereafter, the exposure time subroutine 213 proceeds to block 370.

With reference to FIG. 7B, shown is a second portion of the exposure time subroutine 213. In FIG. 7B, the exposure time subroutine 213 moves from block 370 (FIG. 7a) to block 380 in which a first one of the sensors 131 (FIG. 1) is identified to calculate a new exposure time based on both the saturation exposure time and the exposure time determined by the exposure time subroutine 213 in FIG. 7A. Thereafter, in block 382, the exposure time subroutine 213 calculates an exposure time that is 75% or other percentage of the saturation exposure time for the current sensor. This may be done using linear interpolation given the saturation exposure time and sensor value in addition to the gray level exposure time and corresponding sensor value.

In block 384, the exposure time subroutine 213 determines whether the interpolated exposure time is less than at least 85% or other predefined percentage of the saturation exposure time for the current sensor 131. If such is the case then the exposure time subroutine 213 proceeds to block 386. Otherwise the exposure time subroutine 213 progresses to block 388. In block 386, the current sensor 131 is disqualified as it is presumably malfunctioning due to the fact that the interpolated exposure time is greater than the predetermined percentage of 85% or other value of the saturation exposure time.

Thereafter, the exposure time subroutine 213 proceeds to block 388 as shown. In block 388, it is determined whether the interpolated exposure time has been determined for the last one of the sensors 131 in the sensor array 129. If not, then the exposure time subroutine 213 moves to block 390 in which the next sensor

5 131 in the sensor array 129 is identified. Thereafter, the exposure time subroutine 213 reverts back to block 382.

Assuming that an interpolated exposure time has been determined for the last sensor 131 in block 388, then the exposure time subroutine 213 proceeds to block 392 in which the minimum sensor exposure time for all of the qualified

10 sensors 131 of the sensor array 129 is determined. Thereafter, the exposure time subroutine 213 proceeds to block 394 in which the exposure time to be employed for the sensor array 129 in future operation of the scanner 100 (FIG. 1) is set to the minimum exposure time identified in block 392. Thereafter the exposure time subroutine 213 ends.

With reference to FIG. 8, shown is a flow chart of an exposure time verification subroutine 216 that is executed by the scanner calibration logic 149 to verify the exposure time determined in the exposure time subroutine 213 (FIGS. 7A and 7B). Alternatively, the flow chart of FIG. 8 may be viewed as depicting a number of steps in a method to verify the exposure time determined in the method

15 of FIGS. 7A and 7B. The exposure time verification subroutine 216 generally obtains sensor values from the sensors 131 (FIG. 1) at the optimum exposure time determined by the exposure time subroutine 213. The verification is performed by ensuring that none of the sensor values obtained at the optimum exposure time are within 5% or other percentage of the respective saturation sensor value for the

20 corresponding sensor 131 in the sensor array 129 (FIG. 1). Those sensors 131 that continually generate sensor values that fall within 5% of the respective saturation sensor value are disqualified accordingly.

Beginning with block 400, the exposure time verification subroutine 216 scans the sensors 131 in the sensor array 129 and stores the corresponding

30 sensor values in the memory 106 (FIG. 1). Thereafter, in block 402 the sensor values obtained in block 400 are compared with the corresponding saturation sensor values for each of the sensors 131 in the sensor array 129. In particular, there are three different sensor values for each of the sensors 131 that are

compared with three corresponding saturation sensor values corresponding to the three color channels of the scanner 100 (FIG. 1).

Then, in block 404, the exposure time verification subroutine 216 determines whether any of the sensor values are within a predetermined percentage of the saturation sensor values. The predetermined percentage may be, for example, 5% or other percentage. If such is the case then the exposure time verification subroutine 216 proceeds to block 406. Otherwise, the exposure time verification subroutine 216 proceeds to block 408. In block 406, the exposure time verification subroutine 216 determines whether the exposure time has been reduced a predetermined number of times within the exposure time subroutine 216. Specifically, the exposure time is to be reduced from the optimum exposure time by a predetermined number of times in an attempt to ensure that all sensor values obtained in the scans of block 400 fall below 5% of the corresponding saturation sensor value. In block 406, if the last reduction has not previously taken place, then the exposure time verification subroutine 216 proceeds to block 410 in which the exposure time is reduced by a predetermined percentage of its current value. This predetermined percentage may be, for example, 10% or other value. Thereafter, the exposure time verification subroutine 216 reverts back to block 400.

Assuming that however that the last reduction has taken place in block 406, then the exposure time verification subroutine 216 proceeds to block 412. In block 412 any sensor 131 that still produces a sensor value that is within five percent of its corresponding saturation sensor value is disqualified as presumably such sensors 131 are malfunctioning. Thereafter, the exposure time verification subroutine 216 moves to block 408. In block 408, the exposure time is set at the previous exposure time before the most current reduction has occurred in block 410. If no reduction has occurred when the exposure time verification subroutine 216 reaches block 408, then the initial exposure time employed in block 400 is retained. Thereafter, the exposure time verification subroutine 216 proceeds to block 414 in which the maximum white value of all of the sensor values is determined. This may be accomplished, for example, by illuminating a white scan target and performing a scan of the sensors 131 to obtain the white values from the sensors 131. Thereafter, the maximum white value may be identified. Thereafter, the exposure time verification subroutine 216 ends.

With reference to FIGS. 9A and 9B, shown is a flow chart of the analog verification subroutine 226 that is executed by the scanner calibration logic 149 to verify the analog offset 159 (FIG. 2) and the analog gain 163 (FIG. 2) applied to the programmable gain amplifier 156 (FIG. 2). Alternatively, the flow chart of FIGS. 9A and 9B may be viewed as depicting the steps of a method executed in the scanner 100 (FIG. 1) in order to verify the values of the analog offset 159 and the analog gain 163. Beginning with block 430, the exposure time of the scanner 100 is set to zero to obtain dark values from the sensors 131 (FIG. 1) in the sensor array 129 (FIG. 1). Thereafter, the analog verification subroutine 226 proceeds to block 432 in which the sensors 131 are scanned and the sensor values obtained therefrom are stored in the memory 106 (FIG. 1).

Next, in block 434 the analog verification subroutine 226 determines whether any of the sensor values stored in the memory 106 were "clipped high" as the values generated by the corresponding sensors 131 fell below the minimum threshold of the output of the A/D converter 166. This condition exists if the lowest value generated at the output of the A/D converter 166 is seen for a particular sensor value. Assuming that at least one of the sensor values has been clipped high in block 434, then the analog verification subroutine 226 proceeds to block 436 in which all of the sensors 131 that generated sensor values that were clipped high in block 434 are disqualified in the sensor validity table 153 (FIG. 1). If none of the sensor values generated by the sensors 131 in block 432 are clipped high as determined in block 434, then the analog verification subroutine 226 proceeds to block 438. Likewise, after block 436, the analog verification subroutine 226 also proceeds to block 438.

In block 438 the analog verification subroutine 226 determines whether any of the sensor values obtained in block 432 have been "clipped low" such that they fall above the upper limit of the output of the A/D converter 166. This condition exists if the highest value generated at the output of the A/D converter 166 is seen for a particular sensor value. If not, then the analog verification subroutine 226 skips to block 440. Otherwise the analog verification subroutine 226 proceeds to block 442. In block 442, the analog offset 159 is decreased by a predetermined amount that presumably causes any valid sensors that have been clipped low with respective lock 438 to fall within the operating range of the A/D converter 166.

Thereafter, the analog gain 163 is reduced by a predetermined amount such as, for example, 5% or other percentage of the original analog gain 163.

Next, the analog verification subroutine 226 proceeds to block 446 in which the sensors 131 of the sensor array 129 are scanned and the sensor values
5 obtained therefrom are stored in the memory 106. The analog verification subroutine 226 then proceeds to block 448 in which it is determined whether the same sensors 131 that produce sensor values that were clipped low with respect to block 438 continue to be clipped low. If so, then the analog verification subroutine 226 proceeds to block 450 in which the analog offset 159 and the analog gain 163
10 are returned to their previous values. On the other hand, if the same sensors are not clipped low in block 448, then the analog verification subroutine 226 proceeds to block 440. Likewise, after block 450, the analog verification subroutine 226 also proceeds to block 440. In block 440 the exposure time of the scanner 100 is set to the optimal exposure time determined by the exposure time verification subroutine 216 (FIG. 8).

Thereafter, with reference to FIG. 9B the analog verification subroutine 226 proceeds to block 452 in which the sensors 131 of the sensor array 129 are scanned and the sensor values generated therefrom are stored in the memory 106 (FIG. 1). Thereafter, in block 454, the analog verification subroutine 226
20 determines whether any of the sensor values have been clipped high by the A/D converter 166. If not then the analog verification subroutine 226 proceeds to block 456 in which the current sensor values are maintained in the memory 106 to generate a calibration curve therefrom.

On the other hand, if sensor values are clipped high in block 454, then the
25 analog verification subroutine 226 proceeds to block 458 in which the analog gain 163 is reduced by a predetermined amount such as, for example, 5% or some other percentage. Thereafter, in block 460, the sensors 131 in the sensor array 129 are scanned and the values generated therefrom are stored in the memory 106. Next, in block 462 the analog verification subroutine 226 determines whether all of the
30 same values clipped high in block 454 continue to be clipped high. If not then the analog verification subroutine 226 jumps to block 456. Otherwise, in block 464 the analog gain 163 (FIG. 2) is set back to its previous state and the previous sensor values are restored. Thereafter, the analog verification subroutine 226 proceeds to

block 456. In block 456 the current sensor values are stored in the memory 106 so that they may be accessed to generate a later calibration curve. Thereafter, the analog verification subroutine 226 ends.

Although the scanner calibration logic 149 (FIG. 1) of the present invention is embodied in software executed by general purpose hardware as discussed above, as an alternative the scanner calibration logic 149 may also be embodied in dedicated hardware or a combination of software/general purpose hardware and dedicated hardware. If embodied in dedicated hardware, the scanner calibration logic 149 can be implemented as a circuit or state machine that employs any one of or a combination of a number of technologies. These technologies may include, but are not limited to, discrete logic circuits having logic gates for implementing various logic functions upon an application of one or more data signals, application specific integrated circuits having appropriate logic gates, programmable gate arrays (PGA), field programmable gate arrays (FPGA), or other components, *etc.* Such technologies are generally well known by those skilled in the art and, consequently, are not described in detail herein.

The flow charts of FIGS. 3-6, 7A-B, 8, and 9A-B show the architecture, functionality, and operation of an implementation of the scanner calibration logic 149. If embodied in software, each block may represent a module, segment, or portion of code that comprises one or more action statements in the form of executable instructions or declarations to implement the specified logical function(s). If embodied in hardware, each block may represent a circuit or a number of interconnected circuits to implement the specified logical function(s). Although the flow charts of FIGS. 3-6, 7A-B, 8, and 9A-B show a specific order of execution, it is understood that the order of execution may differ from that which is depicted. For example, the order of execution of two or more blocks may be scrambled relative to the order shown. Also, two or more blocks shown in succession in FIGS. 3-6, 7A-B, 8, and 9A-B may be executed concurrently or with partial concurrence. It is understood that all such variations are within the scope of the present invention. Also, the flow charts of FIGS. 3-6, 7A-B, 8, and 9A-B are relatively self-explanatory and are understood by those with ordinary skill in the art to the extent that software and/or hardware can be created by one with ordinary skill in the art to carry out the various logical functions as described herein.

Also, the scanner calibration logic 149 (FIG. 1) can be embodied in any computer-readable medium for use by or in connection with an instruction execution system such as a computer/processor based system or other system that can fetch or obtain the logic from the computer-readable medium and execute the instructions or action statements contained therein. In the context of this document, a "computer-readable medium" can be any medium that can contain, store, or maintain the scanner calibration logic 149 (FIG. 1) for use by or in connection with the instruction execution system. The computer readable medium can comprise any one of many physical media such as, for example, electronic, magnetic, optical, electromagnetic, infrared, or semiconductor media. More specific examples of a suitable computer-readable medium would include, but are not limited to, a portable magnetic computer diskette such as floppy diskettes or hard drives, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory, or a portable compact disc.

Although the invention is shown and described with respect to certain preferred embodiments, it is obvious that equivalents and modifications will occur to others skilled in the art upon the reading and understanding of the specification. The present invention includes all such equivalents and modifications, and is limited only by the scope of the claims.